# Galactic Accelerators: Perspectives for SGSO

SGSO Workshop Heidelberg

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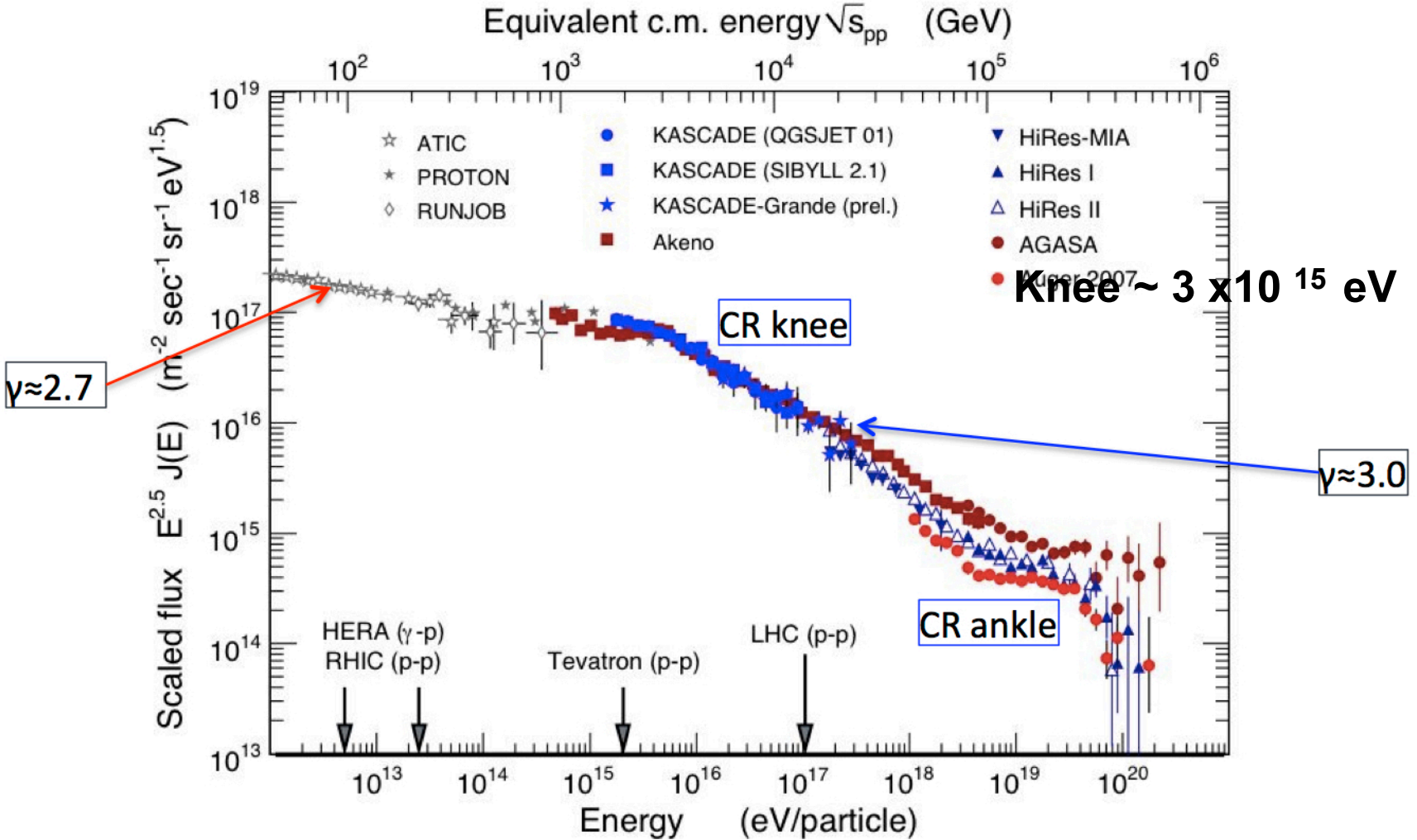
Sabrina Casanova, IFJ-PAN & MPIK

# Outline

- Galactic CR accelerators: state of the art
- A survey for PeVatrons
- SGSO strengths and weakness in hunting Galactic particle accelerators
- Discussion & Outlook

# The Cosmic Ray Spectrum at Earth

- 90% protons, 9% helium, 1% electrons
- Almost featureless spectrum and isotropically distributed up to very high energies
- CRs up to the knee are believed to have a Galactic origin
- Galactic accelerators have to inject particles up to at least the knee at PeV ($10^{15}$ eV) energies, maybe $10^{17}$ eV. The knee for protons might be earlier at about 400-500 TeV (ARGO Collaboration 2015).
- This might be the local CR fog. True for electrons.



# Criteria to define a PeVatron

1. Hard gamma-ray spectrum close to -2
2. No spectral cutoff up to 30-40 TeV which implies a proton spectral cutoff at about 1 PeV

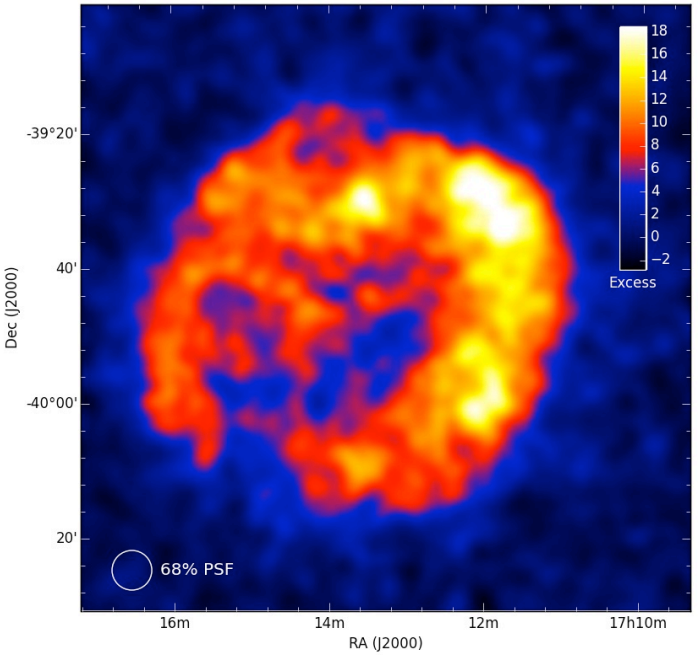
# The first suspect: SNR RX J1713-3946

Young (~1.5 kyr) and nearby (~1 kpc) SNR

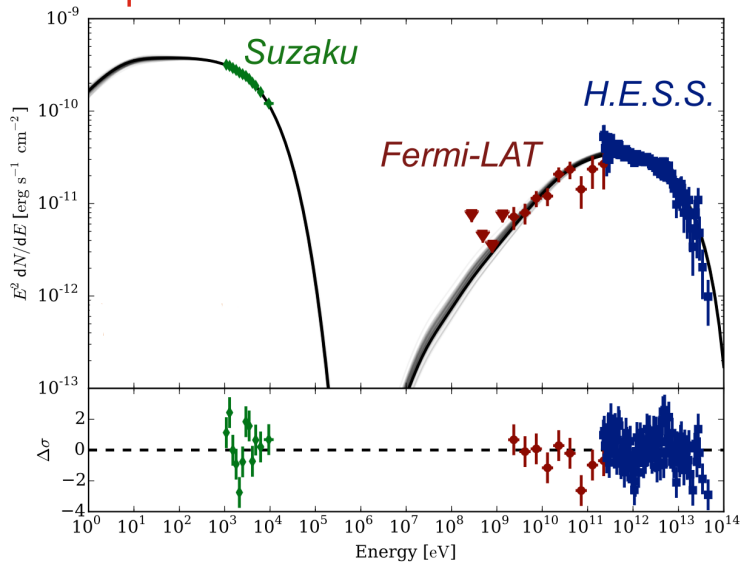
First, and brightest resolved TeV shell

10 years of H.E.S.S. data

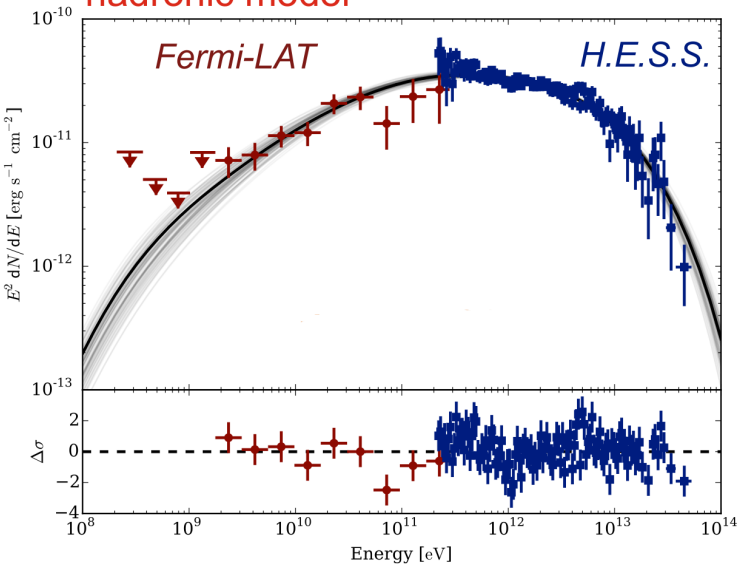
- Factor 2 improvement in statistics over last publication (> 27 000 γ's)
- Spectrum up to ~50 TeV: cuts off ~ 12 TeV
- Spatially resolved spectra!




leptonic model



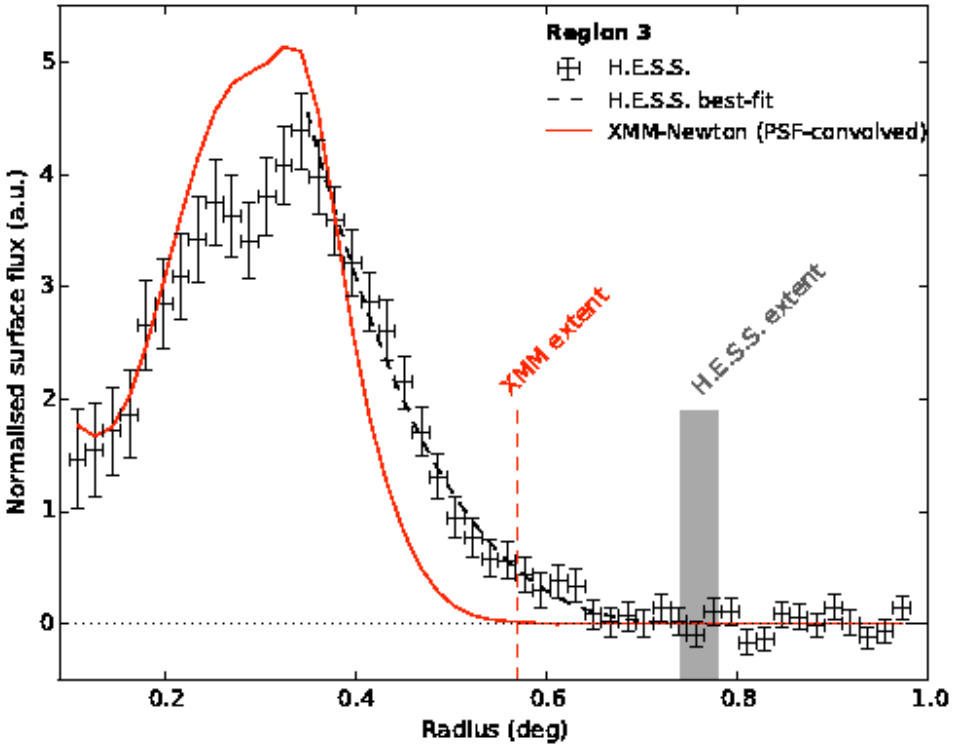

hadronic model




HESS Collaboration2018

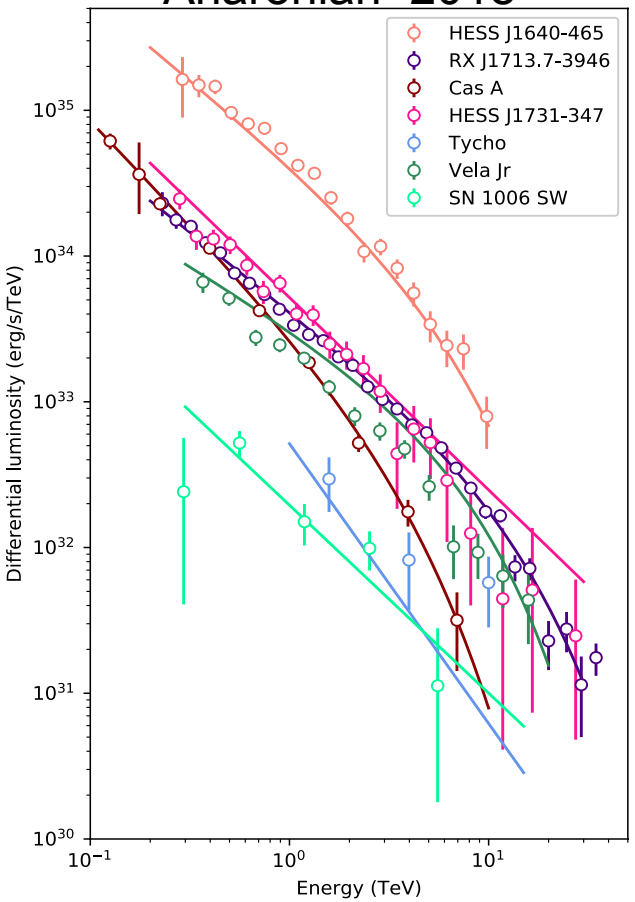
# Spectra of young SNRs

- Cutoffs in the spectra of famous young SNRs (Vela Junior, RXJ1713) ->particle acceleration proceeds up to 100 TeV. No indication of particle acceleration proceeding up to the knee
- Escape -> small chance to detect SNRs when they are PeVatrons
- Possibilities : delayed emission from nearby clouds




HESS Collaboration2018

Aharonian+2018



# SNR energy input in CRs

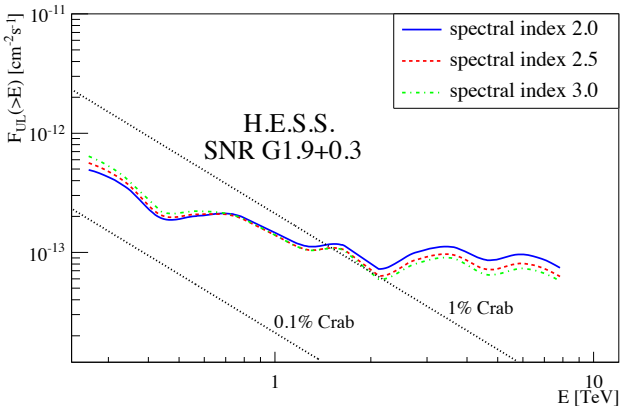
- In order to support the CR population each SNR has to inject about $10^{50}$ erg in protons. This is what we wish to test with our gamma-ray observations but :

  1. hadronic-leptonic degeneracy (unknown density, magnetic and radiation fields)

  2. Even if emission is hadronic, $W_{pp} \propto n^{-1} L_{gamma}$

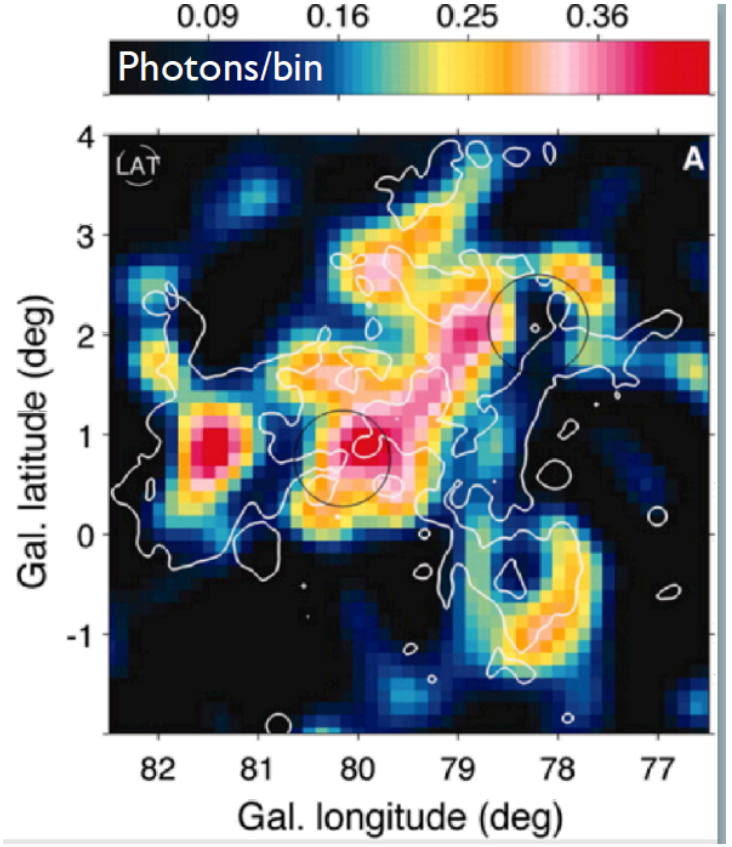
  3. Maybe not all SNR classes inject the same amount of explosion energy in accelerated cosmic rays

- For the non thermal dominated youngest SNR in the Galaxy: G1.9+0.3, age~ 100 yr and highest energy protons cannot propagate beyond several pc. $L_{HESS}$( >1 TeV) < 1e32 erg/s -> <$10^{45}$ erg in protons. Shock speed 14000km/s, Expected synch peak at 20 keV instead only 1 keV _> not efficient accelerator

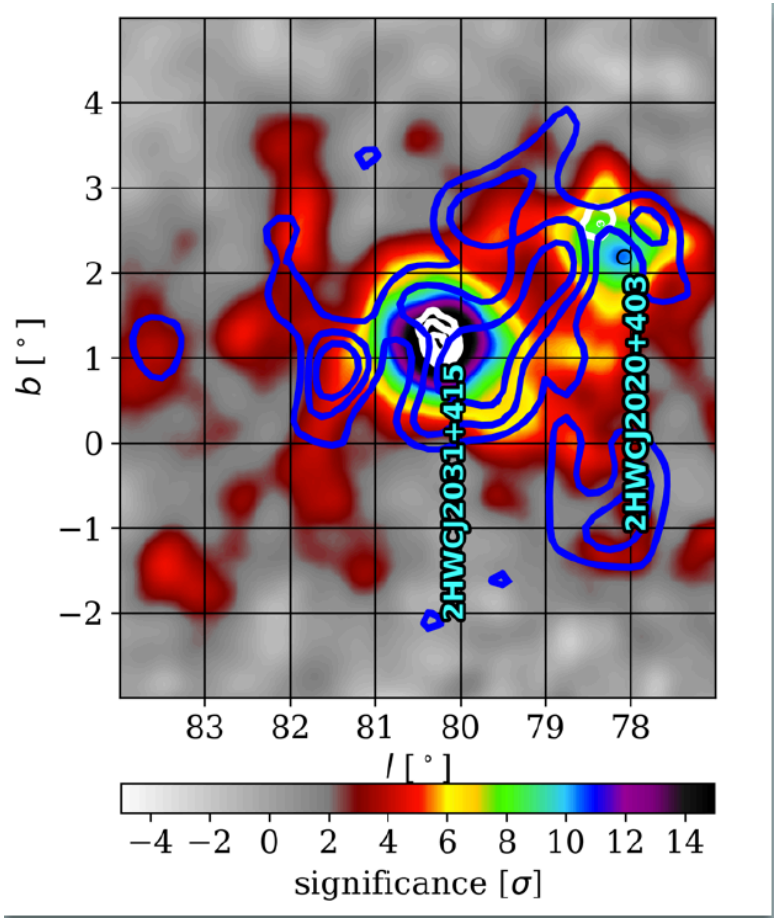


# The Cygnus Cocoon Region

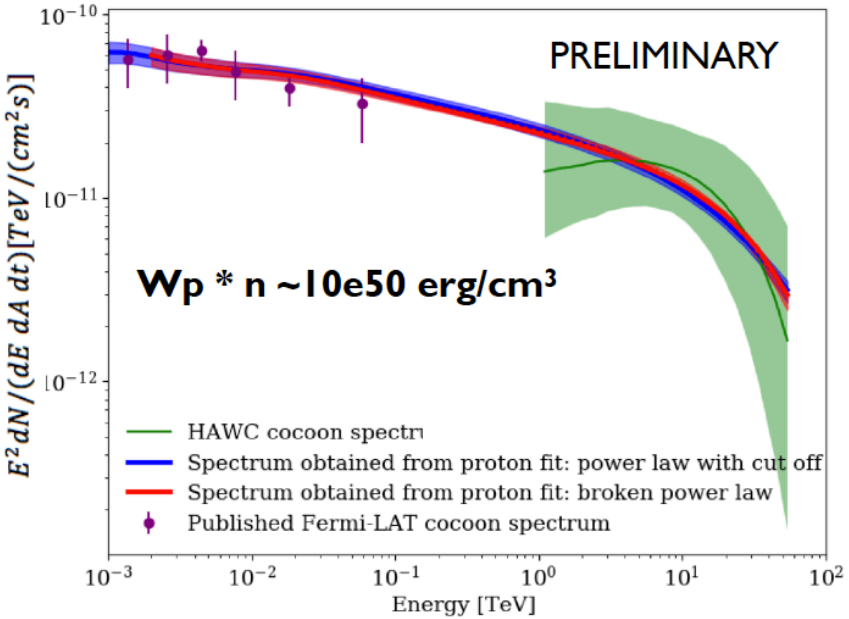
Fermi detected hard and extended emission from Cygnus X, between OB2 and Gamma Cygni SNR. Cocoon of freshly accelerated CRs

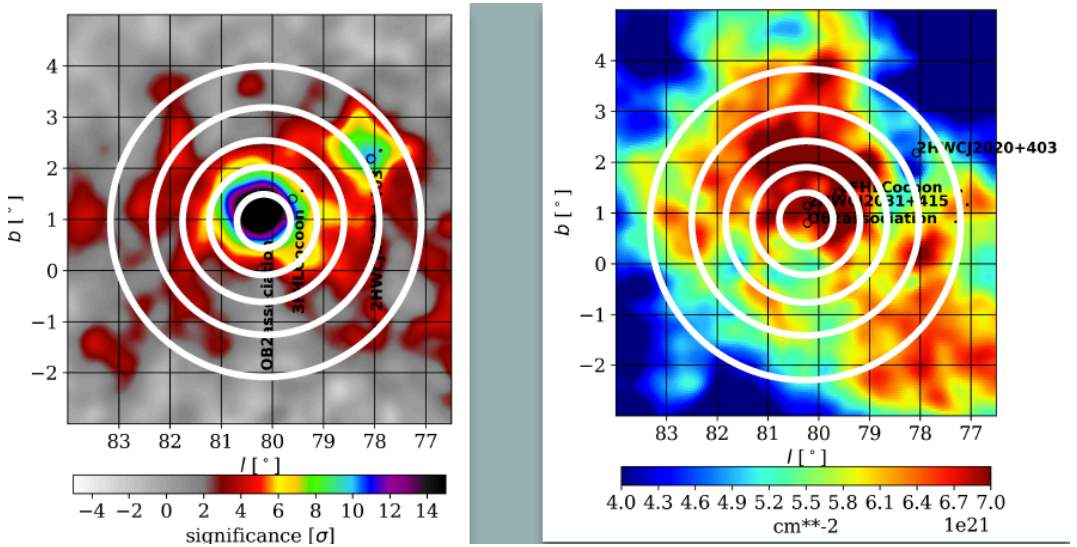



Similar morphology detected at TeV energies



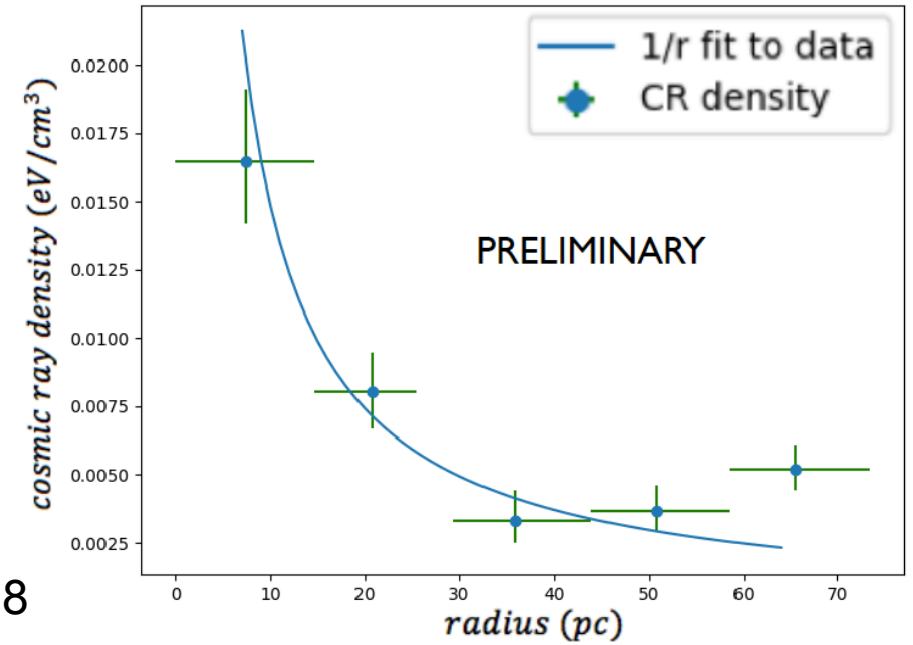
# Spectral and morphological features




Spectrum from GeV to TeV energies without a break -> hadronic mechanism favored

Cygnus offers a zoom view of SFR. HAWC angular resolution good enough to combine gas distribution and gammas -> CR distribution as 1/r

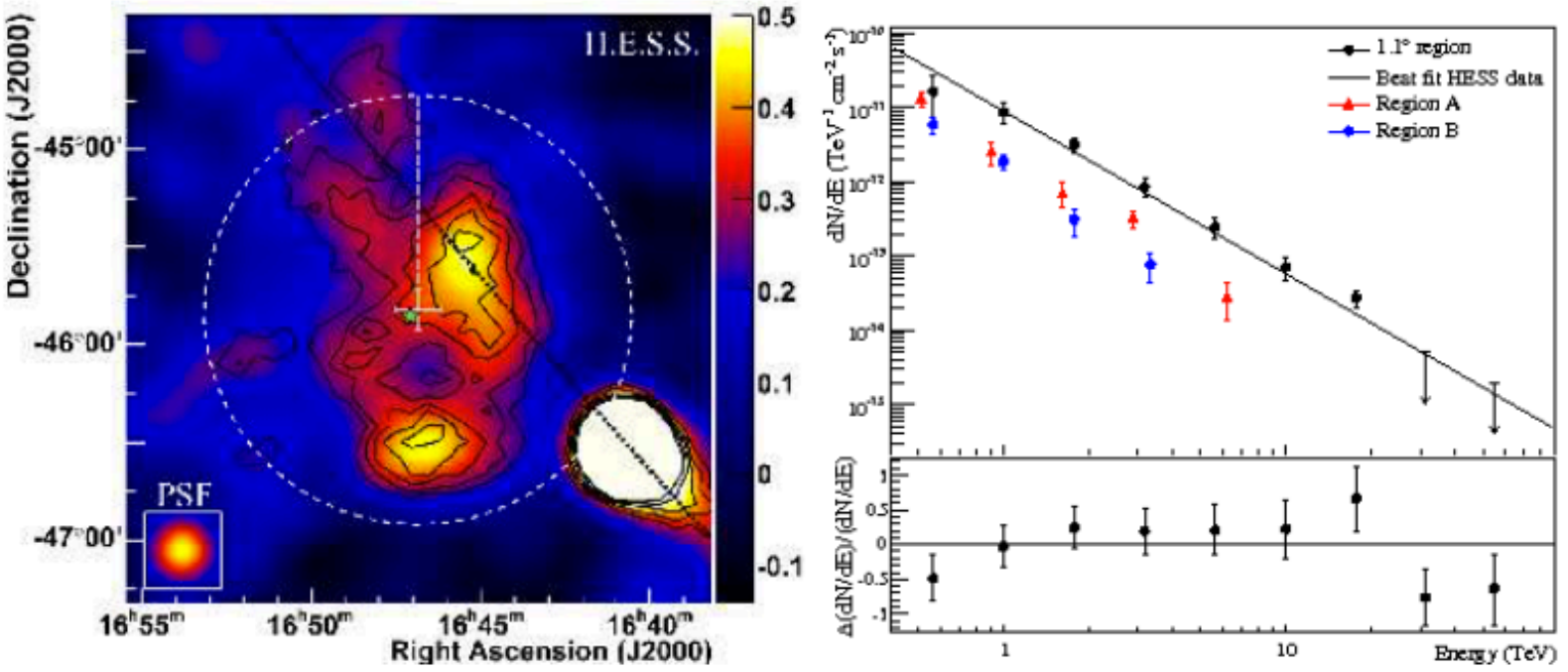



Binita Hona, TeVPa 2018

# Wd1 : A potential PeVatron ?

Stellar Cluster of $10^5$ solar masses at 5 kpc distance
13 WR stars, ~30 hot supergiant stars in 0.5° gas bubble

- Protons interacting with local gas might produce the HESS emission
- **HESS analysis quite challenging because of the large region**



# Systematic search of PeV candidates

- Search of PeV candidates in HESS GPS
  - Hard Spectrum
  - No evidence of cutoffs
- Derive the proton cutoff energies using NAIMA

HESS ...

HESS ...

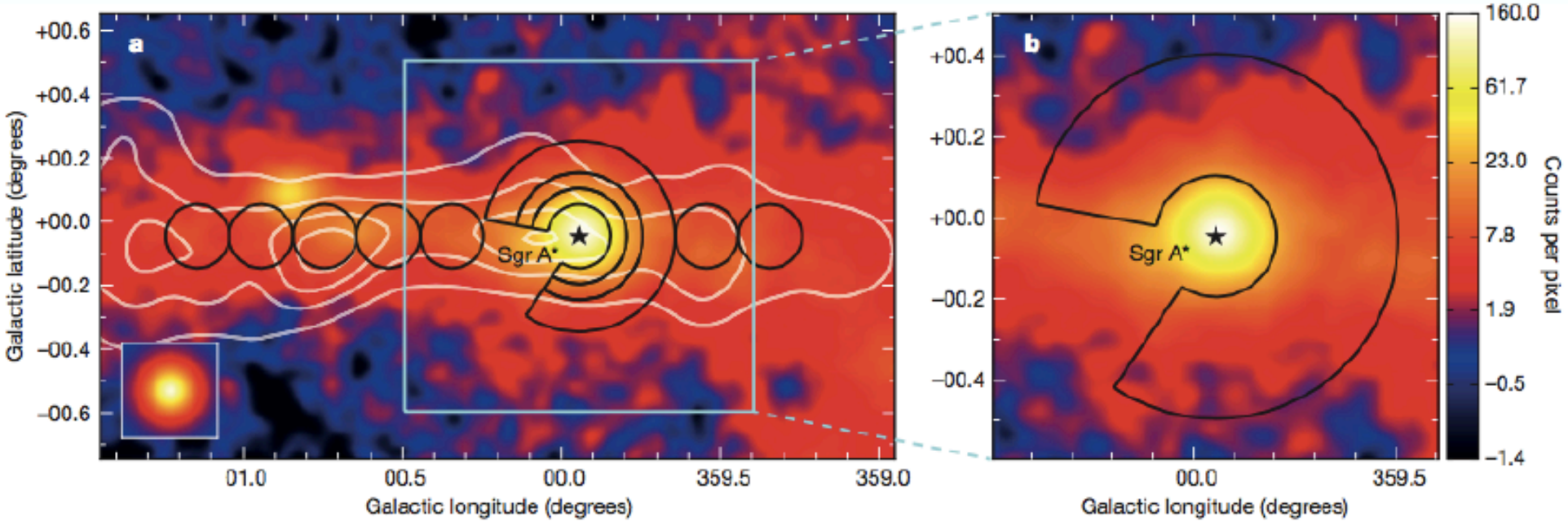
HESS ...

HESS ...

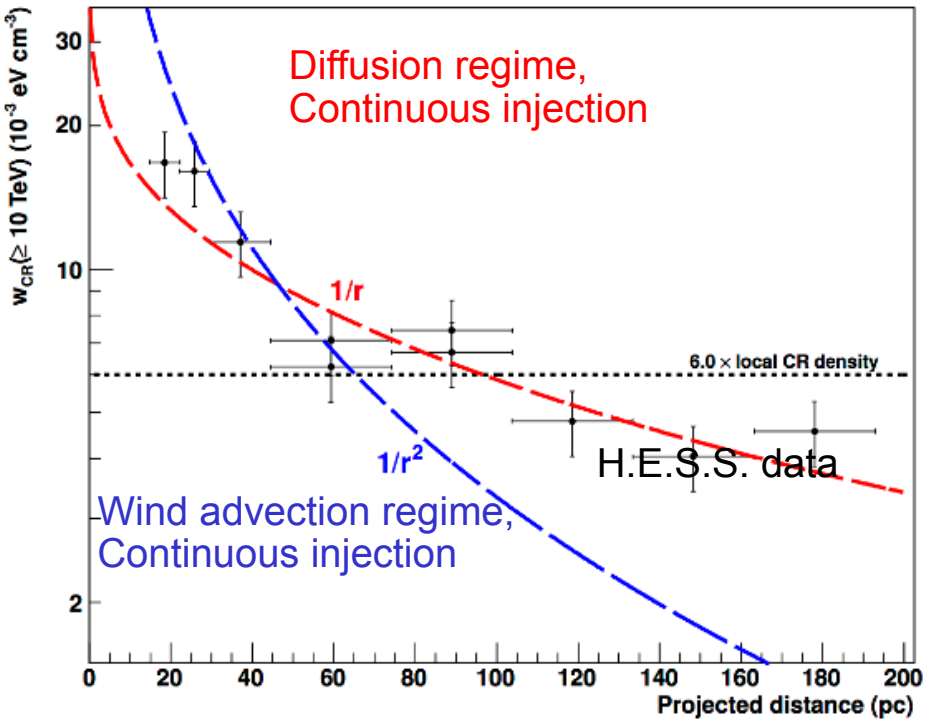
HESS ...

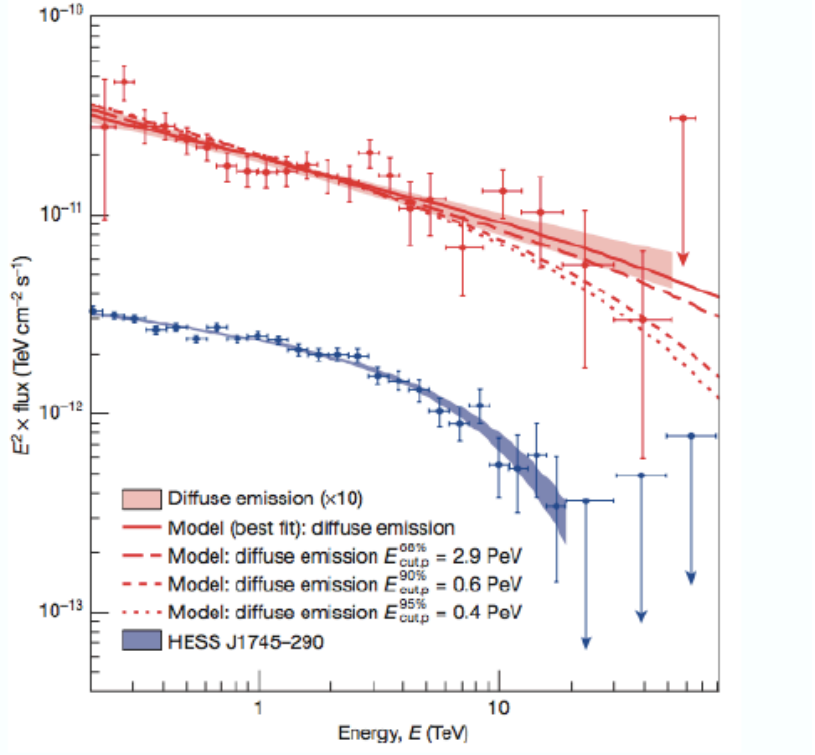
# Acceleration up to PeV energies : Galactic Centre with H.E.S.S.

- Point-like, central source on top of extended (ridge) emission
- Origin of diffuse emission:
  - Interaction of CR (from central BH) with interstellar medium
  - CR acceleration in CMZ (and in particular star forming regions)
  - …



# Galactic Centre with H.E.S.S.: a pevatron



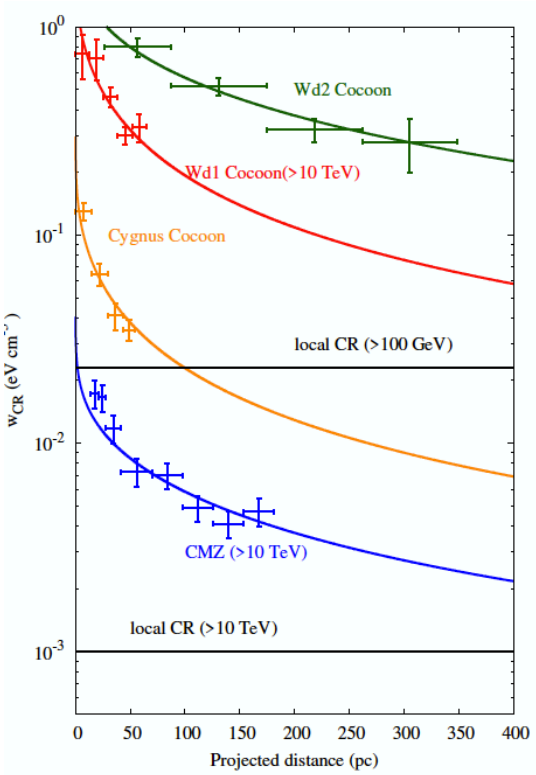

- Central point source: cut-off @ 10 TeV
- Diffuse emission shows no cut-off well > 10 TeV
- Emission profile consistent with propagation of protons accelerated continuously around central black hole and diffusing away.
- Parent proton population up to 1 PeV (2.9 PeV @ 68% CL)

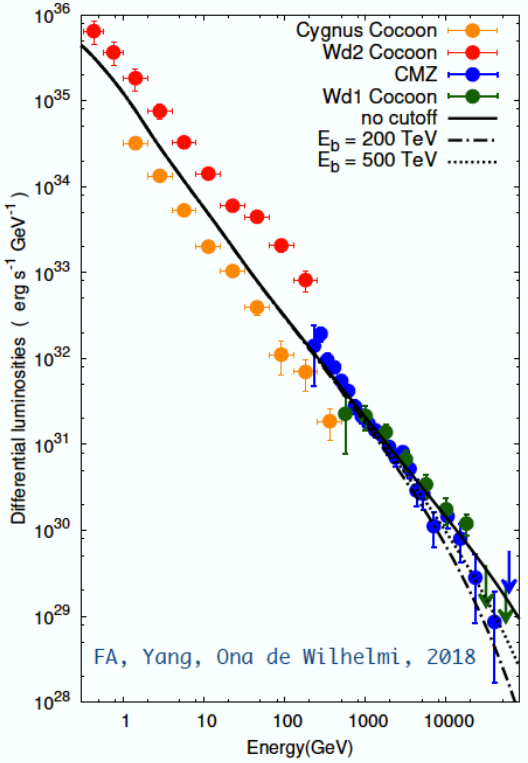
# Young Stellar Clusters

Extended gamma-ray emissions around young star clusters (50 ~ 200 pc). Gamma-ray luminosity ~ 1e36 erg/s.

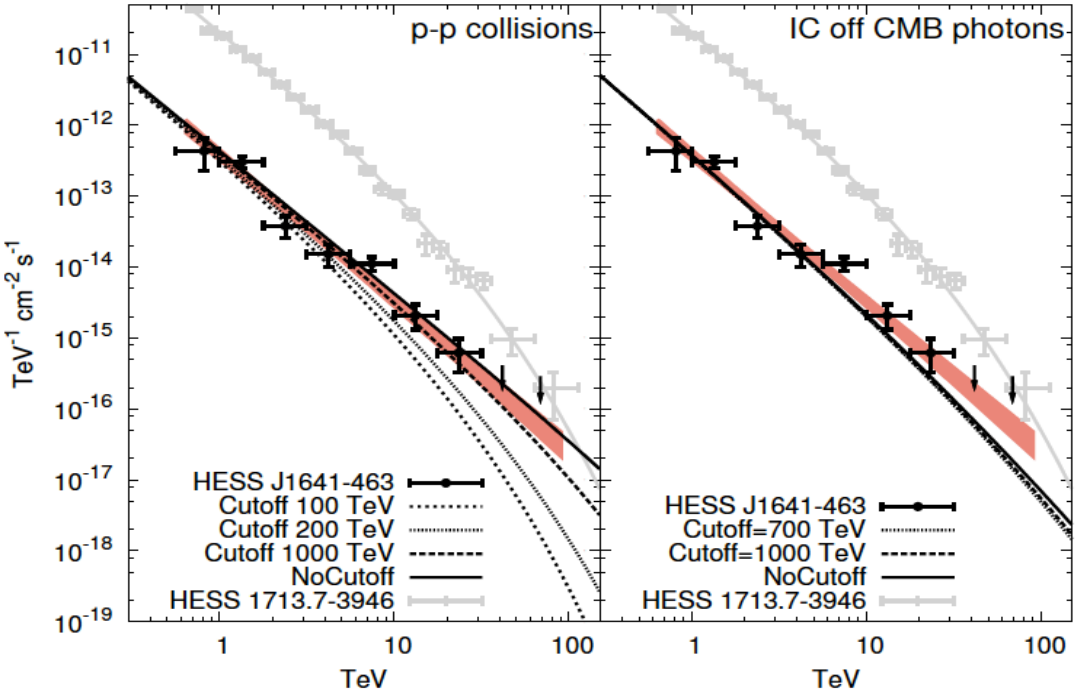
Each source has hard spectrum ~ 2.2, without cutoff

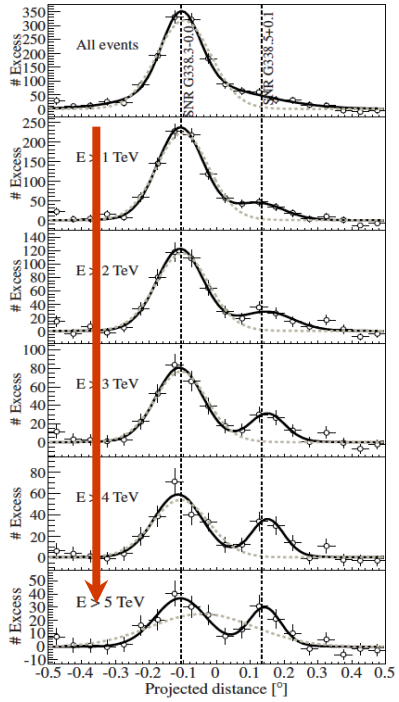
CR distribution derived by gamma-ray profile and gas distributions. 1/r profile implies a Continuous injection in the lifetime of clusters



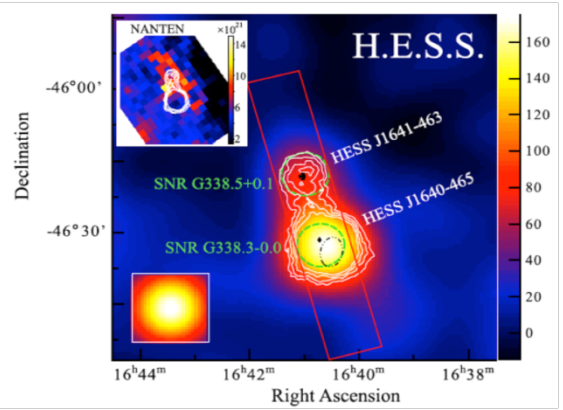



# Unidentified PeVatron candidate




- Very hard spectrum, index 2.07
- No preference for a cutoff
- Data points until 20 TeV
- Lower limit on proton cutoff energy: 100 TeV
- Wpp = $10^{50}$ $n^{-1}$ erg
- Leptonic scenario implies particle spectra up to at least 700 TeV
- Several sources like HESS J1641–463

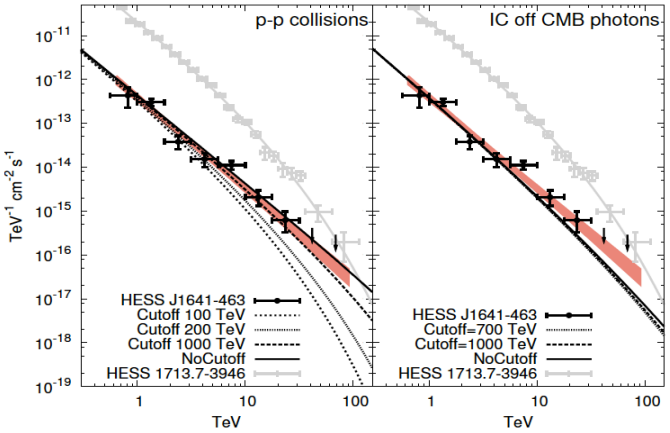


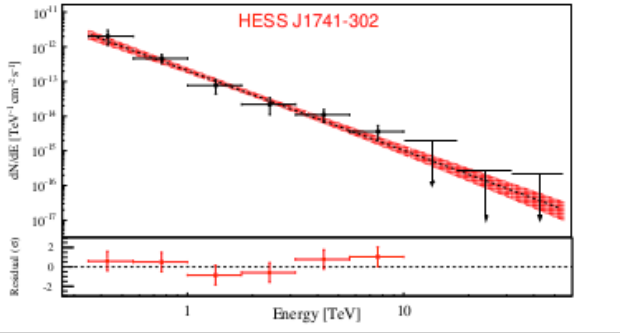

- **HESS J1641–463 (15% Crab > 0.64 TeV)**

HESS Coll 2014

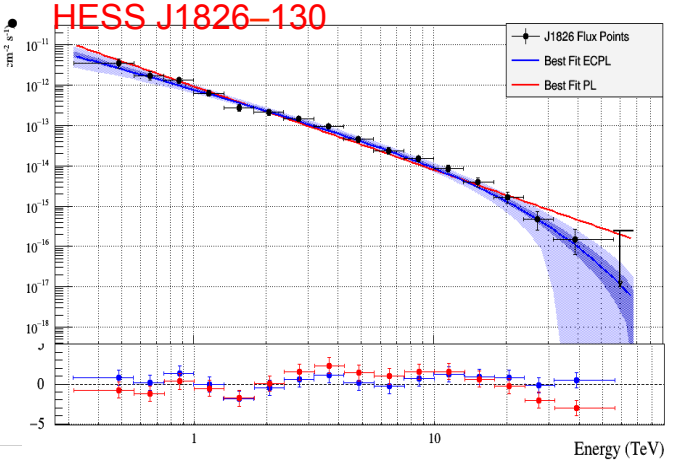
# HESS Spectra of PeV candidates

HESS J1641–463




HESS J1826–130




Anguner+ for HESS 2017

| Source Name | Spectral Model | Normalization (at 1 TeV) $10^{-13} \times \mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{TeV}^{-1}$ | Index | Cut-off Energy (TeV) | Flux (> 1 TeV) (Crab Unit %) |
|---|---|---|---|---|---|
| HESS J1641−463 | PL | $3.91 \pm 0.69_{\mathrm{stat}} \pm 0.8_{\mathrm{sys}}$ | $2.07 \pm 0.11_{\mathrm{stat}} \pm 0.20_{\mathrm{sys}}$ | – | 1.8 |
| HESS J1741−302 | PL | $2.1 \pm 0.4_{\mathrm{stat}} \pm 0.4_{\mathrm{sys}}$ | $2.3 \pm 0.2_{\mathrm{stat}} \pm 0.2_{\mathrm{sys}}$ | – | 1.0 |
| HESS J1826−130 | ECPL | $8.28 \pm 0.68_{\mathrm{stat}} \pm 1.6_{\mathrm{sys}}$ | $1.66 \pm 0.11_{\mathrm{stat}} \pm 0.20_{\mathrm{sys}}$ | $13.5^{+4.7}_{-2.7}$ | 4.0 |

- Difficult analysis at energies beyond 10 TeV where photon statistics is low. Source confusion mightalso  contaminate the observed spectra of VHE γ-ray sources.

# A survey for PeVatrons

Approach until now select a class of sources and investigate the feasibility of such class as contributors to the cosmic ray flux.

With an instrument such as SGSO one could instead use a different approach and look for powerful gammaray emitters in the sky and investigate how these different particles factories contribute to the spectrum of cosmic rays. We expect the contribution of different sources or source classes to be different

For each of the PeV candidates we wish to determine

1) fraction of available energy converted to nonthermal particles (Wpp, we need Lum and gas density)

2) maximum possible energy achieved by individual particles.

# The Ideal Observatory

- Search for sources of cosmic rays close to PeV energies
  → High sensitivity at about 30-40 TeV
- Test spectral break and cutoffs at several TeV
- -> Good energy resolution at several TeVs

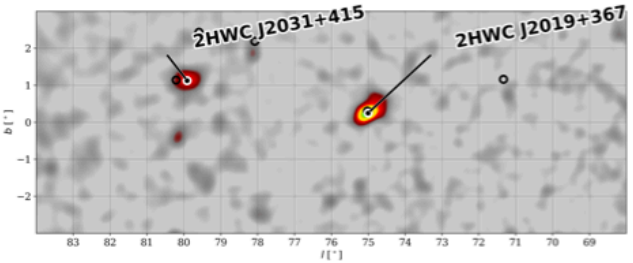
Search for different and possibly unexpected classes of sources -> Unbiased survey

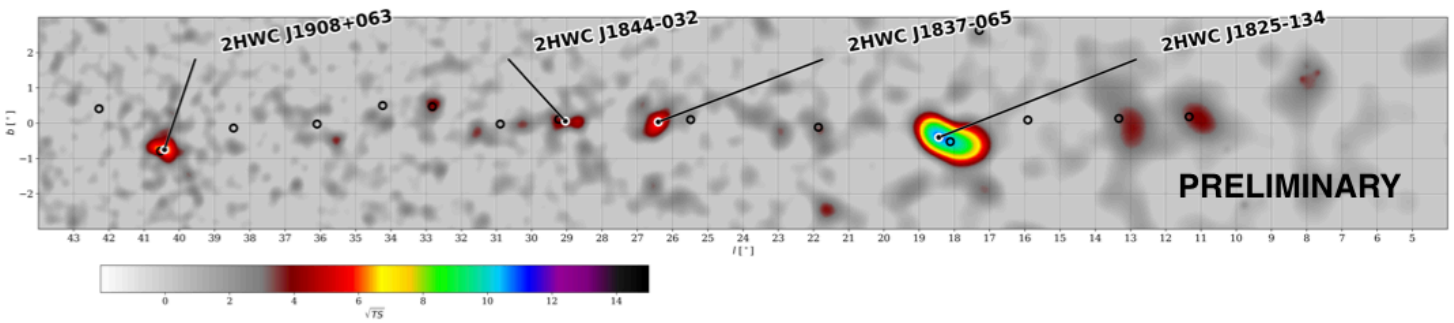
- Resolve sources which might be hidden in the tails of bright sources and compare and correlate with gas surveys -> Good angular resolution at several TeV

# A Survey for PeVatrons

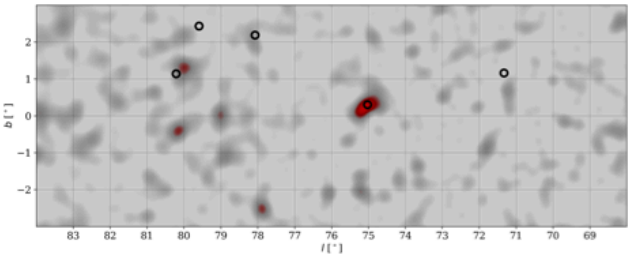
HAWC sky above 56 TeV

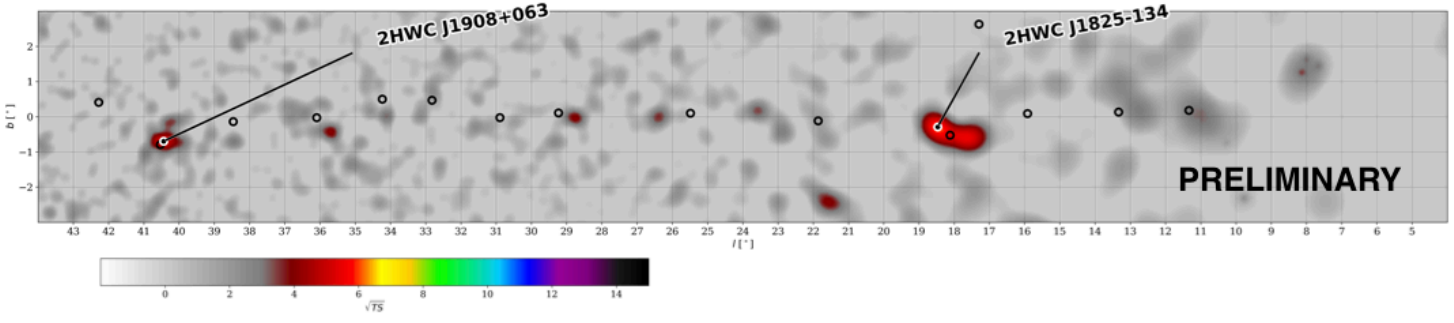
K. Malone I TeVPA 2018




HAWC sky above 100 TeV



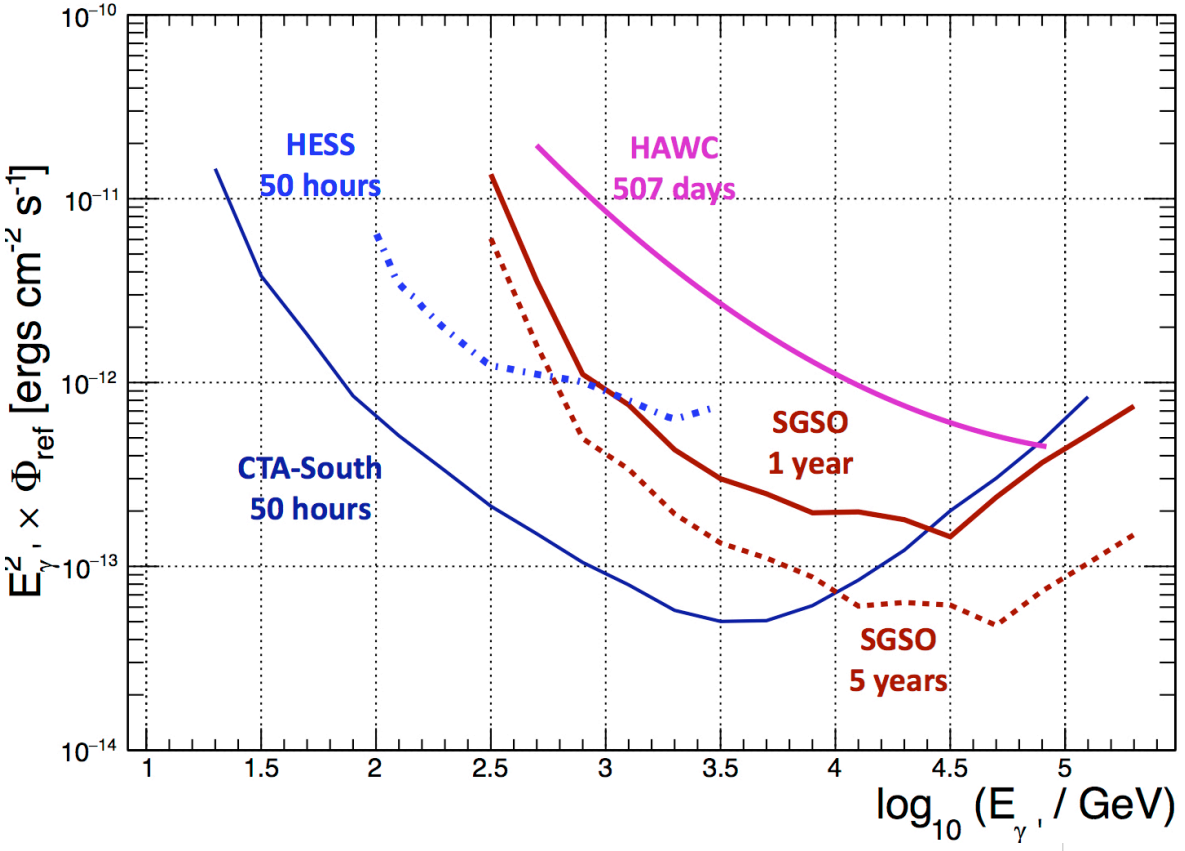



**HAWC has detected the tip of the iceberg but sources like HESS J1741-302 and others below 5% Crab would be missing ! Of course the outtrigers will help a lot in this direction !**

# Performance

Das Bild kann nicht angezeigt werden. Dieser Computer verfügt möglicherweise über zu wenig Arbeitsspeicher, um das Bild zu öffnen, oder das Bild ist beschädigt. Starte

*HAWC Angular Resolution*




*Point Source Sensitivity*

# Current Gas Surveys

**new high-resolution (<arcmin) ISM surveys :**

**Southern Hemisphere:**

Mopra CO(1-0) http://newt.phys.unsw.edu.au/mopraco/

ASAKP (GASKAP) HI/OH – https://www.atnf.csiro.au/research/GASKAP/index.html

**Northern Hemisphere:**

Nobeyama FUGIN CO(1-0) - https://academic.oup.com/pasj/article/69/5/78/4060573
VLA THOR HI - http://www2.mpia-hd.mpg.de/thor/Overview.html

# HAWC+SGSO Coverage

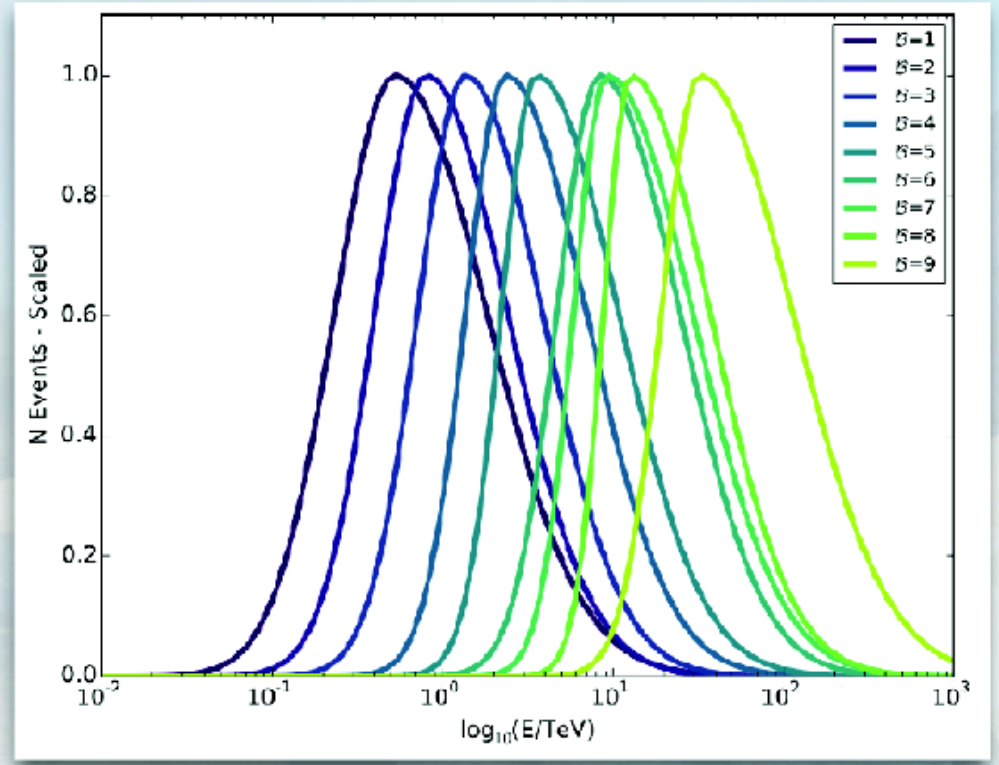

Assuming SGSO is at 25 deg South

# SGSO Strengths

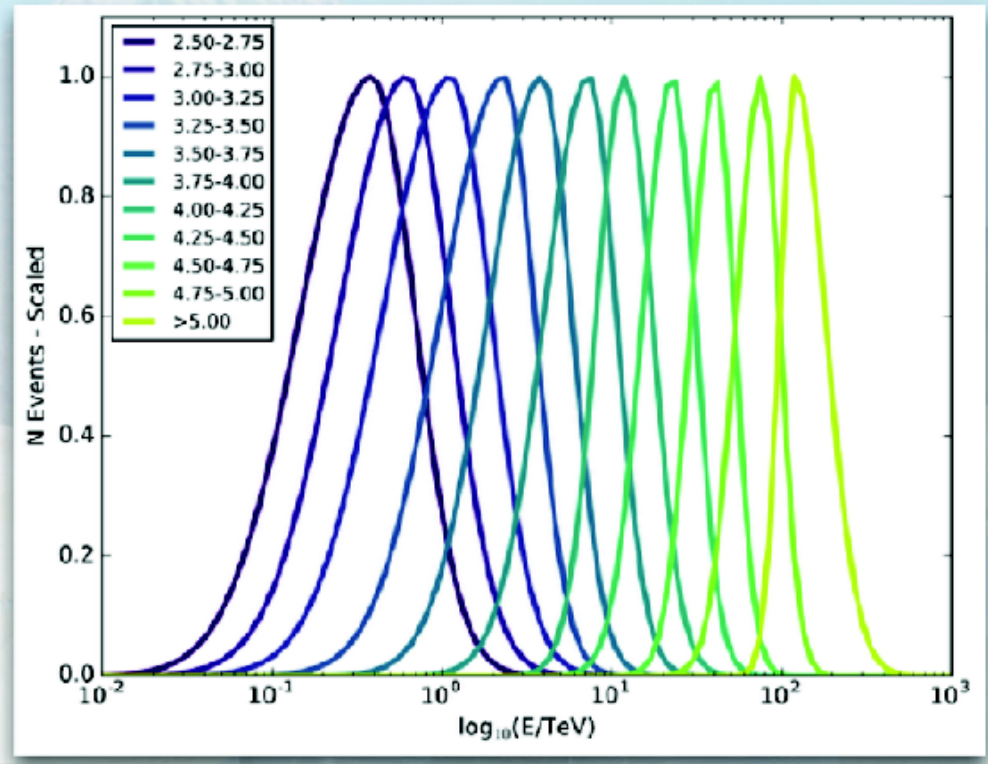
- Multi TeV reach
- Good sensitivity for extended sources
- Good angular resolution in the highest energy regime
- Unbiased survey and large coverage of the sky

WHAT ABOUT ENERGY RESOLUTION ?

# Energy resolution in HAWC



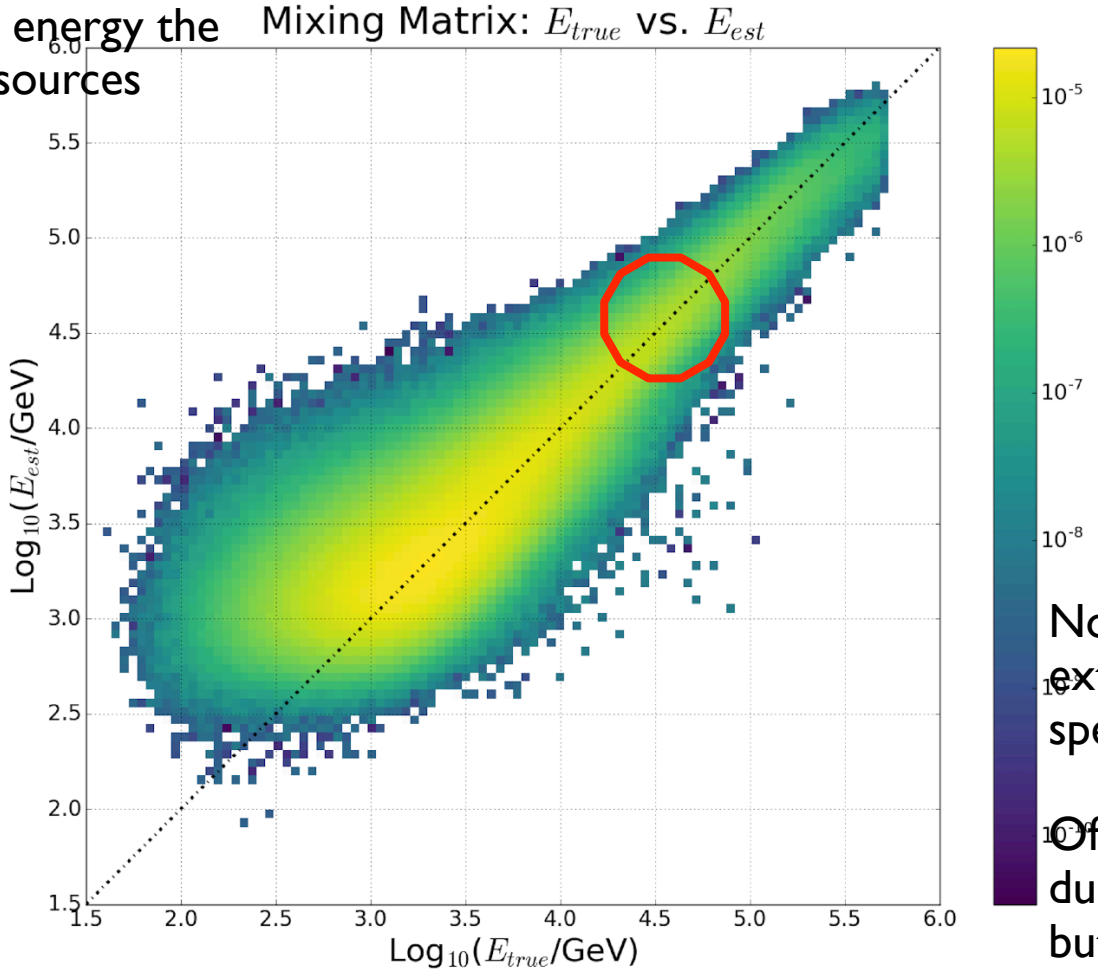

Old method arXiv: 1701.01778v1




New method

# Energy resolution in HAWC. Mixing matrix

Cutoff at 30 TeV imply proton cutoff at about 1 PeV. Of course the higher energy the better but most sources become too faint.




K. Malone I TeVPA 2018

Not ideal spectroscopy, extremely important to detect spectral break and cutoffs !

Of course one has physical limits due to the detection technique but there one should strive for improvements.

# Outlook and discussion

- Galactic CR accelerators : State of the art
- A survey for PeVatrons
- Strengths and weakness of SGSO
- Some missing items such as SNR population (Cristofari+2017) and extended emission around SNRs (CR escape, gas clumps...)
- Discussion....